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WHAT IS CLAIMED IS:

1. A method of determining the range between a target plane and a monitoring plane comprising the steps of:

generating model data corresponding to selected parameters describing flight path characteristics of the target plane;

collecting actual flight path data of the target plane;

generating an error measurement from said model data and said actual flight path data;

adjusting said model data to reduce said error measurement; and

calculating the range from said model data.

2. The method of Claim 1 wherein said selected parameters include measurements of the target plane's velocity and position.

3. The method of Claim 1 wherein said actual flight path information includes measurements of elevation and azimuth of the target plane relative to a predefined coordinate system.

4. The method of Claim 1, and further including the steps of:

determining an azimuth sighting error by subtracting a measurement of azimuth of the target based on said model data from a measurement of azimuth based on said actual target flight path data; and

determining an elevation sighting error by subtracting a measurement of elevation of the target based on said model data from a measurement of the azimuth based on said actual target flight path data.

5. The method of Claim 4 wherein said error measurement includes a mean squared sighting error determined as an average of the sum of the squares of said azimuth sighting error and said elevation sighting error over a plurality of intervals at which actual target flight path information is collected.

6. The method of Claim 5 wherein said error measurement further includes a velocity penalty based on a deviation between an estimated velocity of the target derived from said model data and a predetermined nominal velocity.

7. The method of Claim 5 wherein said error measurement further includes an azimuth position penalty based on a deviation between said azimuth sighting error and a predetermined azimuth sighting error bandwidth.

8. The method of Claim 5 wherein said error measurement further includes an elevation position penalty based on a deviation between said elevation sighting error and a predetermined elevation sighting error bandwidth.

9. The method of Claim 5 wherein said error measurement further includes a maximum range position penalty imposed when the estimated range of the target plane derived from said model data is in excess of a predetermined maximum acquisition range.

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10. A method of determining the range between a target plane and a monitoring plane comprising the steps of:

generating model data corresponding to selected parameters describing flight path characteristics of the target plane;

collecting actual flight path data of the target plane;

generating an error measurement from said model data and said actual flight path data; 103

calculating a perturbation model, said perturbation model indicating a change in said model data which reduces said error measurement;

adjusting said model data in accordance with said perturbation model; and

calculating the range from said model data.

11. The method of Claim 10 and further including the step of deriving a second-order Taylor series approximation of an error measurement equation used to calculate said error measurement.

12. The method of Claim 11 wherein said step of calcuating the perturbation model includes the steps of:

determining a perturbation direction which minimizes said second-order Taylor Series approximation of said error measurement; and

determining an optimum perturbation magnitude along said perturbation direction which minimizes said error measurement.

13. The method of Claim 12 wherein said step of determining said perturbation direction includes the steps of:

determining a gradient vector of the error measurement equation;

determining a matrix having elements which are the second derivatives of the error measurement equation with respect to said model parameters;

determining a perturbation vector such that said matrix multiplied by perturbation vector equals said gradient vector; and

defining a perturbation direction in the direction of said perturbation vector.

14. The method of Claim 12 wherein said step of determining an optimum perturbation magnitude includes the steps of:

defining lower and upper magnitude boundaries encompassing said optimum perturbation;

determining values of said error measurement equation at said lower and upper magnitude boundaries;

determining values of the derivative of said error measurement equation at said lower and upper magnitude boundaries;

calculating a polynomial approximation of said error measurement equation;

calculating an intermediate magnitude at which a derivative of said polynomial approximation is equal to zero;

calculating a value of the derivative of the error measurement equation at said intermediate magnitude;

setting said lower magnitude boundary equal to said intermediate magnitude if said value of said derivative of the error measurement equation at said intermediate magnitude is negative;

setting said upper magnitude boundary equal to the intermediate magnitude if said value of the derivative of the error measurement equation at said intermediate magnitude is positive;

setting said optimum perturbation magnitude equal to said intermediate magnitude if said value of the

derivative of the error measurement equation at said intermediate magnitude is equal to zero; and

setting said optimum perturbation magnitude equal to an average of said lower and upper magnitude boundaries if said lower and upper magnitude boundaries are within a predetermined range.

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15. A method of determining the range between a target plane and a monitoring plane comprising the steps of:

collecting actual flight path data of the target plane;

generating model data corresponding to selected parameters describing flight path characteristics of the target plane;

adjusting the flight path of the monitoring plane in a direction optimizing ranging performance;

generating an error measurement from said model data and said actual flight path data;

adjusting said model data to reduce said error measurement; and

calculating the range from said model data.

16. The method of Claim 15 wherein said step of adjusting the flight path includes the steps of:

determining sighting vectors between the monitoring plane and the target plane at a plurality of time intervals;

calculating a sighting matrix W such that

$$W = (1/N) \sum_{n=0}^{N-1} \underline{w}_n \underline{w}_n^T$$

where $\underline{w}_n$ is a sighting vector at time t_n and N is the number of time intervals over which the summation is calculated; and

adjusting the flight path of the monitoring plane in a direction given by an eigenvector corresponding to the smallest eigenvalue of matrix W.

17. The method of Claim 2, further including the step of generating initial model data.

18. The method of Claim 17, wherein said initial model data includes an initial target velocity v_T calculated as:

$$\underline{v}_T = [\langle \underline{u}_1, \underline{v}_O \rangle - \rho_O \beta \cos((\theta_D/2) + \phi)]\, \underline{u}_1 + [\langle \underline{u}_2, \underline{v}_O \rangle - \rho_O \beta \sin((\theta_D/2) + \phi)]\, \underline{u}_2 + [\langle \underline{u}_3, \underline{v}_O \rangle]\underline{u}_3$$

where:

$\underline{u}_1$, $\underline{u}_2$, $\underline{u}_3$ - eigenvectors corresponding to largest, second largest and third largest eigenvalues of matrix W.

$\underline{v}_O$ - ownship velocity vector

θ_D - angle between θ_O and θ_i, calculated as $[12\lambda_2]^{1/2}$, where λ_2 is the second largest eigenvalue of matrix W.

ϕ - angle between $\underline{w}_O$ and $\underline{v}_r$, where $\underline{v}_r$ is the relative velocity vector.

19. The method of Claim 17, wherein said initial model data includes as initial target position $\underline{c}$ calculated as:

$$\underline{c} = \rho_O \left(\cos((\theta_D/2)\underline{u}_1 - \sin(\theta_D/2)\underline{u}_2\right)$$

where:

$$\rho_O = [-B-(B^2-AC)^{\frac{1}{2}}]/A$$

where $A = \beta^2$

$$B = \beta[\langle\underline{u}_2, \underline{v}_O\rangle \sin((\theta_D/2)+\phi) - \langle\underline{u}_1, \underline{v}_O\rangle \cos((\theta_D/2)+\phi)]$$

$C = \mu_O{}^2 - \mu_T{}^2$ (μ_O and μ_T are the speeds of the ownship and target)

$$\text{and } \beta = [(f^2 + s_1{}^2)/(t_1{}^2(1 + S_1))]^{\frac{1}{2}}$$

where $S_1 = \tan(\theta_1)$; $S_2 = \tan(\theta_2)$

$$f^2 = [(t_1/t_2)^2 (1 + S_1{}^2)^2 - 2(t_1/t_2)(1+S_1{}^2)(S_1{}^2+(S_1/S_2)) + (S_1{}^2+(S_1/S_2))^2]\, S_2{}^2/(S_2-S_1)$$

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20. Apparatus for determining the range between a target plane and a monitoring plane comprising:

a receiver for collecting actual flight path data of the target plane;

a processing device for performing arithmetic calculations;

said processing device operable to generate model data corresponding to select parameters describing flight path characteristics of the target plane;

said processing device further being operable to generate an error measurement from said model data and said actual flight path data and to adjust said model data to reduce said error measurement in order to calculate the range from said model data.

21. The apparatus of Claim 20 wherein said processing device comprises a plurality of processing elements including microprocessors and arithmetic coprocessors.

22. The apparatus of Claim 20 wherein said processing device is operable to generate measurements of the target plane velocity and position.

23. The apparatus of Claim 20 wherein said receiver collects measurements of elevation and azimuth of the target plane relative to a predefined coordinate system.

24. The apparatus of Claim 20 wherein said processing device is operable to calculate an azimuth sighting error determined by calculating an estimated azimuth measurement based on said model data and subtracting said estimated azimuth from a measurement of azimuth based on said actual target flight path data, said processing device being further operable to calculate an elevation sighting error determined by calculating an estimated elevation of the target based on said model data and subtracting said estimated elevation from a measurement of azimuth based on said actual flight path data.

25. The apparatus of Claim 24 wherein said error measurement includes a means squared sighting error determined as the average of the sum of the squares of the azimuth sighting error and the elevation sighting error over a plurality of intervals at which actual target flight path information is collected.

26. The apparatus of Claim 25 wherein said error measurement further includes a velocity penalty based on deviation between an estimated velocity of the target derived from said model data and a predetermined nominal velocity.

27. The apparatus of Claim 25 wherein said error measurement further includes an azimuth position penalty based on the deviation between said azimuth sighting error and a predetermined azimuth sighting error bandwidth.

28. The method of Claim 25 wherein said error measurement further includes an elevation position penalty based on the deviation between said elevation sighting error and a predetermined elevation sighting error bandwidth.

29. The method of Claim 25 wherein said error measurement further includes a maximum range position penalty imposed when an estimated range of the target plane derived from the model data is in excess of a predetermined maximum range.

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30. An apparatus for determining the range between the target plane and a monitoring plane comprising:

means for collecting actual flight path data of the target plane;

means for generating model data corresponding to selected parameters describing flight path characteristics of the target plane;

means for generating an error measurement from said model data and said actual flight path data;

means for calculating a perturbation model, said perturbation model indicating a change in said model data which reduces said error measurement;

means for adjusting said model data in accordance with said perturbation model; and

means for calculating the range from said model data.

31. The apparatus of Claim 30 and further comprising means for calculating said error measurement from a second-order Taylor series of approximation of an error measurement equation.

32. The apparatus of Claim 31 wherein said means for adjusting said model data comprises:

means for determining a direction for perturbating said model data in which said second-order Taylor series approximation of said error measurement is minimized; and

means for determining an optimum magnitude along said perturbation direction which minimizes said error measurement.

33. The apparatus of Claim 32 wherein said means for determining said perturbation direction includes:

means for determining a gradient vector of the error measurement equation;

means for determining a matrix having elements comprising the second derivatives of the error measurement equation with respect to the model parameter; and

means for determining a perturbation vector such that said matrix multiplied by said perturbation vector equals said gradient vector.

34. The apparatus of Claim ~~32~~ wherein said means for determining an optimum perturbation magnitude includes:

means for choosing initial lower and upper magnitude boundaries encompassing said optimum perturbation;

means for determining a value of the error measurement equation at said lower and upper magnitude boundaries;

means for determining a value of the derivative of said error measurement equation at said lower and upper magnitude boundaries;

means for calculating a polynomial approximation of said error measurement equation from said values of said error measurement equation and said values of the derivative of said error measurement equation at said lower and upper magnitude boundaries;

means for calculating an intermediate magnitude at which the derivative of said polynomial approximation is equal to zero;

means for calculating a value of the derivative of the error measurement equation at said intermediate magnitude;

means for adjusting said lower and upper magnitude boundaries, said lower boundary set equal to said intermediate magnitude if said value of the derivative of the error measurement equation is negative, and said upper magnitude boundary set equal to said

intermediate magnitude if said value of the derivative of the error measurement equation is positive; and

said optimum perturbation magnitude set equal to a value of the average of said lower and upper magnitude boundaries if said lower and upper boundaries are within a predetermined range.

Sub A6

35. An apparatus for determining the range between the target plane and a monitoring plane comprising:

a receiver for collecting actual flight path data of the target plane;

a processor for generating model data corresponding to selected parameters describing flight path characteristics of the target plane; and

said processor calculating a flight path of the monitoring plane which optimizes ranging performance.

36. The apparatus of Claim 35 wherein:

said receiver collects data from which sighting vectors between the monitoring plane and the target plane may be determined at a plurality of time intervals;

said processor is operable to calculate a sighting matrix W such that

$$W = (1/N) \sum_{n=0}^{N-1} \underline{w}_n \underline{w}_n^T$$

where $\underline{w}_n$ is sighting a vector at times t_n and N is the number of time intervals over which the summation is calculated; and

said processor is operable to calculate an eigenvector corresponding to the smallest eigenvalue of

said matrix W, said eigenvalue giving an optimum direction for said flight path.

37. The apparatus of Claim 20 wherein said processing device is operable to calculate initial model data.

38. The apparatus of Claim 37 wherein said processing device is operable to calculate initial target velocity data v_T such that

$$\underline{v}_T = [\langle \underline{u}_1, \underline{v}_O \rangle - \rho_O \beta \cos((\theta_D/2) + \phi)]\, \underline{u}_1 + [\langle \underline{u}_2, \underline{v}_O \rangle - \rho_O \beta \sin((\theta_D/2) + \phi)]\, \underline{u}_2 + [\langle \underline{u}_3, \underline{v}_O \rangle]\underline{u}_3$$

where:

$\underline{u}_1$, $\underline{u}_2$, $\underline{u}_3$ - eigenvectors corresponding to largest, second largest, and third largest eigenvalues of matrix W

$\underline{v}_O$ - ownship velocity vector

θ_D - angle between θ_O and θ_i, calculated as $[12\lambda_2]^{\frac{1}{2}}$, where λ_2 is the second largest eigenvalue of matrix W.

ϕ - angle between $\underline{w}_O$ and $\underline{v}_r$, where $\underline{v}_r$ is the relative velocity vector.

39. The apparatus of Claim 37 wherein said processing device is operable to calculate initial target position data $\underline{c}$ such that

$$\underline{c} = \rho_O \left(\cos((\theta_D/2)\underline{u}_1 - \sin(\theta_D/2)\underline{u}_2\right)$$

where:

$$\rho_O = [-B-(B^2-AC)^{1/2}]/A$$

where $A = \beta^2$

$$B = \beta[\langle \underline{u}_2, \underline{v}_O \rangle \sin((\theta_D/2) + \phi) - \langle \underline{u}_1, \underline{v}_O \rangle \cos((\theta_D/2) + \phi)]$$

$C = \mu_O^2 - \mu_T^2$ (μ_O and μ_T are the speeds of the ownship and target)

and $\beta = [(f^2 + s_1^2)/(t_1^2(1 + S_1))]^{1/2}$

where $S_1 = \tan(\theta_1)$; $S_2 = \tan(\theta_2)$

$$f^2 = [(t_1/t_2)^2 (1 + S_1^2)^2 - 2(t_1/t_2)(1+S_1^2)(S_1^2+(S_1/S_2)) + (S_1^2+(S_1/S_2))^2]\, S_2^2/(S_2-S_1)^2$$